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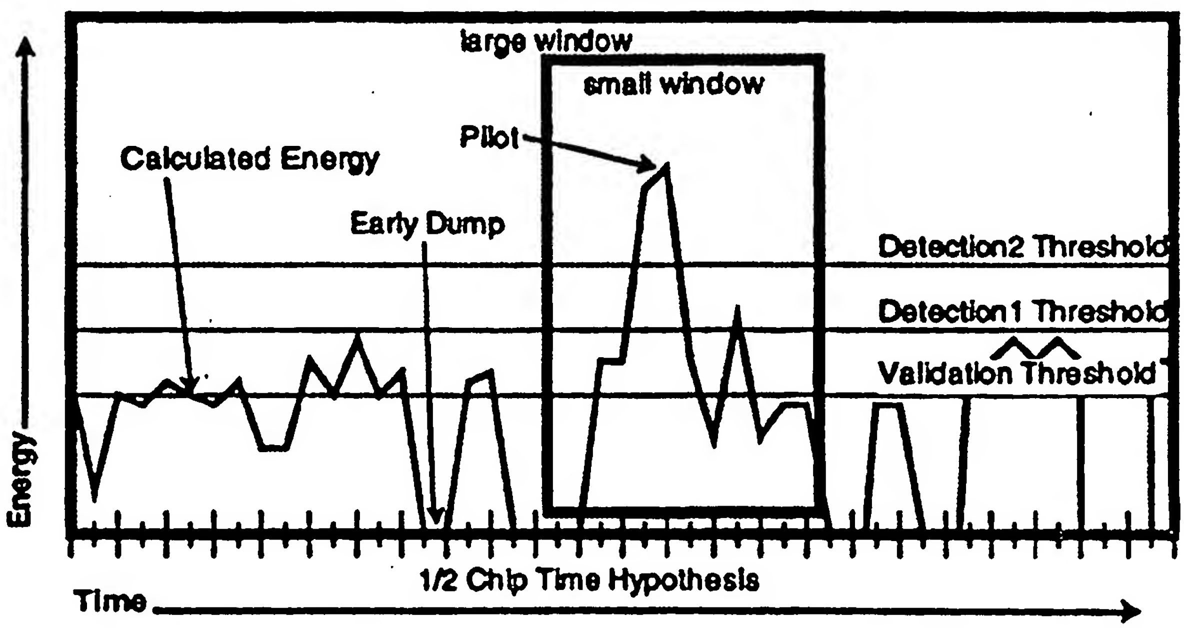
Published
With international search report.

(54) Title: METHOD AND APPARATUS FOR PERFORMING CODE ACQUISITION IN A CDMA COMMUNICATIONS SYSTEM



(57) Abstract

A novel and improved method of acquisition in a spread spectrum communication system is presented. In the present invention, a large window of PN chip offset hypotheses are searched which are generated by a PN sequence generator (20) under the control of a searcher controller (18). The energy of the despread sequence which is despread by a despreader (6) is found that might indicate the presence of the pilot signal in a threshold comparer (16) having one of the chip offsets of the large search window, then a search of a subset of offset hypotheses, or small window, is searched under the control of searcher controller (18).

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SK	Slovakia
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US	United States of America
UZ	Uzbekistan
VN	Viet Nam

Method and Apparatus for Performing Code Acquisition in a CDMA Communications System

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to spread spectrum communications. More particularly, the present invention relates to a novel and improved method and apparatus for acquisition in spread spectrum communication environment.

II. Description of the Related Art

The use of code division multiple access (CDMA) modulation techniques is one of several techniques for facilitating communications in which a large number of system users are present. Other multiple access communication system techniques, such as time division multiple access (TDMA) and frequency division multiple access (FDMA) are known in the art. However, the spread spectrum modulation technique of CDMA has significant advantages over these modulation techniques for multiple access communication systems. The use of CDMA techniques in a multiple access communication system is disclosed in U.S. Patent No. 4,901,307, issued February 13, 1990, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS", assigned to the assignee of the present invention, of which the disclosure thereof is incorporated by reference herein.

CDMA by its inherent nature of being a wideband signal offers a form of frequency diversity by spreading the signal energy over a wide bandwidth. Therefore, frequency selective fading affects only a small part of the CDMA signal bandwidth.

Space or path diversity is obtained by providing multiple signal paths through simultaneous links from a mobile user through two or more cell-sites. Furthermore, path diversity may be obtained by exploiting the multipath environment through spread spectrum processing by allowing a signal arriving with different propagation delays to be received and processed separately. Examples of the utilization of path diversity are illustrated in U.S. Patent No. 5,101,501, issued March 31, 1992, entitled "SOFT HANDOFF IN A CDMA CELLULAR TELEPHONE SYSTEM", and

U.S. Patent No. 5,109,390, issued April 28, 1992, entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM", both assigned to the assignee of the present invention and incorporated by reference herein.

The deleterious effects of fading can be further controlled to a certain extent in a CDMA system by controlling transmitter power. A system for cell-site and mobile unit power control is disclosed in U.S. Patent No. 5,056,109, issued October 8, 1991, entitled "METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM", Serial No. 07/433,031, filed November 7, 1989, also assigned to the assignee of the present invention. The use of CDMA techniques in a multiple access communication system is further disclosed in U.S. Patent No. 5,103,459, issued April 7, 1992, entitled "SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM", assigned to the assignee of the present invention, of which the disclosure thereof is incorporated by reference herein.

The aforementioned patents all describe the use of a pilot signal used for acquisition. The use of a pilot signal enables the mobile station to acquire local base station communication system in a timely manner. The mobile station gets synchronization information and relative signal power information from the received pilot signal.

In an ideal system where the hardware set up time is zero, a search window of one hypothesis would be ideal. However, because it takes time to set up the hardware to conduct searches windows of hypotheses are tested. The longer the time required to set up the hardware, the larger the necessary window size. In complex systems a searcher is required to search a window of many hypotheses and upon finding a candidate synchronized sequence, will repeat the search over the window a predetermined number of times to verify the synchronization. This process requires an unacceptably long acquisition time. The present invention provides a method and apparatus for accelerating the time required to acquire a the pilot signal in a mobile communications system.

SUMMARY OF THE INVENTION

The present invention is a novel and improved method and apparatus that reduces the mobile unit forward link acquisition time. It is an advantage of the present invention to minimize the total time for

acquisition by speeding up the search methodology without incurring excessive penalties for false acquisition.

A method for determining and verifying the phase of a pilot channel in a spread spectrum communication system comprising the steps of determining a set of calculated energy values for a first predetermined large window set of PN sequence hypotheses; comparing the set of calculated energy values against a first threshold value; determining a second set of calculated energy values for a predetermined small window set of PN sequence hypotheses wherein the small window PN sequence hypotheses are a subset of the large window set of PN sequence hypotheses when at least one energy value of the set of calculated energy values exceeds the first threshold value; and determining the phase of the pilot channel in accordance with the second set of calculated energy values.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

Figure 1 is a block diagram of the present invention;

Figure 2 is an illustration of the energy versus chip offset for a fixed window;

Figure 3 is a flowchart illustrating a fixed window size implementation of the searcher algorithm;

Figure 4 is an illustration of the energy versus chip offset for the zoom window of the present invention; and

Figure 5 is an illustration of the energy versus chip offset for the zoom window implementation of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In a spread spectrum communication system, a pilot signal is used to synchronize a mobile station in phase and frequency to the transmissions of a base station. In the exemplary embodiment, the spread spectrum communication system is a direct-sequence spread spectrum communication system. Examples of such systems are discussed in U.S. Patent No. 5,056,109 and U.S. Patent No. 5,103,459. In a direct-sequence

spread spectrum communication system, the transmitted signals are spread over a frequency band greater than the minimum bandwidth necessary to transmit the information by modulating a carrier wave by the data signal, then modulating the resulting signal again with a wideband spreading signal. In a pilot signal, the data can be looked at as an all ones sequence.

The spreading signal is typically generated by a linear feedback shift register, the implementation of which is described in detail in the aforementioned patents. The spreading signal can be viewed as a rotating phasor of the form:

$$s(t) = Ae^{-\omega t+\phi} \tag{1}$$

In order to acquire, the mobile station must synchronize to the received signals from the base station in both phase, ϕ, and in frequency, ω. The object of the searcher operation is to find the phase of the received signal, ϕ. After finding the phase of the spreading signal, ϕ, the frequency is found in using a demodulation element that has hardware for both phase and frequency tracking. The method by which a mobile finds the phase of the received signal is by testing a set of phase hypotheses, referred to as a window and determining if one of the hypothetical phase hypotheses, also referred to as offset hypotheses, is correct.

Turning now to the drawings, Figure 1 illustrates the apparatus of the present invention. Upon power up, a spread spectrum signal is received at antenna 2. The objective of the apparatus is to gain synchronization between pseudorandom noise (PN) sequences generated by PN sequence generator 20 and the received spread spectrum signal which is spread by identical PN sequences of unknown phase.

In the exemplary embodiment, both the modulator that spreads the pilot signal and PN generator 20 are a maximal length shift register which generate the PN code sequences for spreading and despreading the pilot signal respectively. Thus, the operation of obtaining synchronization between the codes used to despread the received pilot signal and the PN spreading code of the received pilot signal involves determining the time offset of the shift register.

The spread spectrum signal is provided by antenna 2 to receiver 4. Receiver 4 downconverts the signal and provides the signal to despreading element 6. Despreading element 6 multiplies the received signal by the PN code generated by PN generator 20. Due to the random noise like nature of

the PN codes the product of the PN code and the received signal should be essentially zero except at the point of synchronization.

However, due to a lack of synchronization on a chip level and due to introduced noise this is not the case, which gives rise to false alarm situations where the mobile station may believe that it has successfully acquired the pilot signal but in realty it has not. In order to give higher certainty to the determined condition of successful lock, the test is repeated a number of times. The number of times the test is repeated is determined by searcher controller 18. Searcher controller 18 may be implemented in hardware using a microprocessor or micro-controller or alternatively in software.

Searcher controller 18 provides an offset hypothesis to PN generator 20. In the exemplary embodiment, the received signal is modulated by quadrature phase shift keying (QPSK), so PN generator provides a PN sequence for the I modulation component and a separate sequence for the Q modulation component to despreading element 6. Despreading element 6 multiplies the PN sequence by its corresponding modulation component and provides the two output component products to coherent accumulators 8 and 10.

Coherent accumulators 8 and 10 sum the product over the length of the product sequence. Coherent accumulators 8 and 10 are responsive to signals from searcher controller 18 for resetting, latching and setting the summation period. The sums of the products are provided from summers 8 and 10 to squaring means 14. Squaring means 14 squares each of the sums and adds the squares together.

The sum of the squares is provided by squaring means 12 to non-coherent combiner 14. Noncoherent combiner 14 determines an energy value from the output of squaring means 12. Noncoherent accumulator 14 serves to counteract the effects of a frequency discrepancy between the base station transmit clocks and the mobile station receive clock and aids in the detection statistic in a fading environment. If one knows that the frequency of the two clocks are exactly the same and that there is no deep fades then the ideal approach is to integrate the sequence over the entire accumulation period in the form:

$$E=\left(\sum_{n=1}^{N} I(n)PNI(n)\right)^2+\left(\sum_{n=1}^{N} Q(n)PNQ(n)\right)^2$$

(2)

, where PNI (n) and PNQ(n) can be ±1.

If, however, there is a probability of frequency mismatch or fading, then the correlator sacrifices some of its detection statistic in order to have a more robust correlation technique of the form:

$$E = \sum_{k=1}^{M} \left\{ \begin{array}{l} \left(\sum_{n=1}^{N} I(n+(k-1)N) \cdot PNI(n+(k-1)N) \right)^2 + \\ \left(\sum_{n=1}^{N} Q(n+(k-1)N) \cdot PNQ(n+(k-1)N) \right)^2 \end{array} \right\}$$

(3)

Searcher controller 18 provides the value M to noncoherent accumulator 14.

Noncoherent accumulator 14 provides the energy signal to comparison means 16. Comparison means 16 compares the energy value to predetermined thresholds supplied by searcher controller means 18. The results of each of the comparisons is then fedback to searcher controller 18. Search controller 18 examines the comparisons and determines whether the window contains likely candidates for the correct offset then the widow is rescanned in accordance with the method of using a zoom window.

In order to illustrate the benefits of using the zoom window technique an example of the method using a fixed window size is provided. Figure 2 illustrates a graph of the energy values versus the chip time hypothesis. In the exemplary embodiment a window contain 56 chip hypotheses. The window illustrates the use of a two level threshold test. The thresholds denoted are detection threshold and validation threshold.

Figure 3 illustrates a conventional method used for scanning windows of a fixed number of hypotheses. The flow starts in block 40, where the operation described in relation to Figure 1 is performed to give comparison results indicated in Figure 2. If the window is "swept" and no hypothesis's energy exceeds the detection threshold (THM) block 42, then searcher controller 18 would begin sweeping the next window blocks 47 and block 40.

However, if there are points on the calculated energy curve which do exceed the detection threshold (THM), then the flow proceeds to the validation phase in block 44. In block 44, the same large window is swept

again, and this time the calculated energy is compared against the lower threshold value, validation threshold (THV). If in block 42 the maximum energy detected does not exceed the threshold, then a next large window is swept in blocks 47 and 40. The flow proceeds to block 48 which determines if validation for twenty consecutive windows has occurred. If fewer than N validation tests, where for example N equals twenty, have been conducted then the flow proceeds to block 44 and the large window is swept again. However, after N consecutive successful validation tests then the pilot is determined to be acquired.

Now turning to Figure 4, the calculated energy curve is illustrated and the use of the zoom window of the present invention is illustrated. When a peak is detected, the searcher controller zooms in on that peak and tests hypotheses in a smaller set close to the hypothesis that gave rise to the detected peak.

Turning to Figure 5, a flowchart illustrating the method by which the searcher of the present invention operates. In the improved method of the present invention a three stage acquisition technique is used. In block 80, the large window is swept. Searcher controller 18 examines the comparison results to determine if there is a peak greater than Detection Threshold (THM). If no peak is detected greater than THM then the flow returns to block 80 and a new window is swept.

When a peak greater than THM is found in a large window, then the flow proceeds to block 84. This time only a sweep in the smaller set of hypotheses around the detected peak is performed. This smaller set of hypotheses is illustrated in Figure 4 as the small window. The use of the small window for the second verification is to reduce the acquisition time by greatly reducing the time to test for false alarm, the state wherein the mobile initially believes it has narrowed in on the phase, but in reality has not. The time it takes to perform this second test is reduced proportionally to the ratio between the number of hypotheses in the small window versus the number of hypotheses in the large window. Noncoherent accumulations are performed in on the data from this small window search in order to have a better operating characteristic.

Then in block 86, if there is energy greater than Detection threshold 2 (THM2), the search enters the validation phase. If no energy greater than the threshold THM2 is found then the flow returns to block 80 and a new large window is searched.

If in block 86, it is determined that there is a calculated energy value greater than threshold 2 (THM2), then the flow proceeds to block 88. There

are three conditions under which validation is stopped: (1) the sweep fails V_f in a row, (2) the frequency estimate doubles back on itself from on 100ms sample to the next, or (3) determine that the pilot has been acquired. In validation, the signal at the peak is demodulated. In block 88, the received signal is demodulated in accordance with the hypothesis of the peak. The results of the demodulated signal are analyzed to determine if they are in lock, and if so then acquisition is complete. If the demodulated results indicate that the signal is not in lock, then the flow proceeds to block 92.

In Block 92, the calculated energy values for the small window are compared to the validation threshold value (THV). If in Block 92, there are calculated energy values in the small window which exceed the validation threshold then the flow proceeds to block 94 where a counter variable is set to zero and then the flow proceeds back to block 88 and the flow continues as previously described.

If in Block 92, there are no calculated energy values in the small window which exceed the validation threshold then the flow proceeds to block 96 where a counter variable is incremented and then the flow proceeds back to block 98 which checks if the validation test has failed twice in a row. If the validation test has failed V_f times in a row, then the flow proceeds to block 80 and a new large window is scanned. If the validation test has not failed twice in a row, then the flow proceeds to block 88 and the operation continues as described previously.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

CLAIMS

1. In a direct sequence spread spectrum communication system, a method for determining PN sequence synchronization, comprising the steps of:

calculating a first set of signal correlation energy values for a first set of temporally offset PN sequences;

comparing said first set of signal correlation energy values against a first threshold value;

selecting a second set of PN sequences in accordance with said first set of signal correlation energy values;

calculating a second set of signal correlation energy values for said second set of PN sequences, wherein said second set of PN sequences are a subset of said first set of PN sequences; and

selecting said synchronized PN sequence from said second set of PN sequences in accordance with said second set of signal correlation energy values.

2. The method of Claim 1 further comprising the step of comparing said second set of signal correlation energy values against a second threshold value.

3. The method of Claim 2 further comprising the step of demodulating a received signal in accordance with said selected synchronized PN sequence.

5. The method of Claim 1 further comprising the step of receiving and downconverting a broadcast signal to provide a received signal.

6. The method of Claim 5 wherein said step of calculating a first set of signal correlation energy values comprises the steps of:

despreading said received signal in accordance with each PN sequence of said first set of PN sequences to provide a first set of despread signals; and

calculating a signal correlation energy value for each of said despread signals.

7. The method of Claim 1 further comprising the step of generating said first set of PN sequences.

8. The method of Claim 7 wherein said the step of generating said first set of PN sequences, comprises the steps of:

providing a control signal; and

generating a PN sequence of said first set of PN sequences in accordance with said control signal.

9. The method of Claim 8 wherein said control signal is a temporal offset and said step of generating a PN sequence comprises outputting said PN sequence from a shift register in accordance with said temporal offset.

10. The method of Claim 1 wherein said first set of PN sequences comprise quadrature PN_I and PN_Q sequences.

11. The method of Claim 10 wherein said step of calculating said signal correlation energy value for each of said despread signals comprises the steps of:

generating said PN_I and PN_Q sequences;

despreading an I component of a received signal and a Q component of a received signal by said PN_I and PN_Q sequences to provide corresponding despread I and Q components of said received signal;

coherently accumulating said despread I components of said received signal to provide an accumulated I component;

coherently accumulating said despread Q components of said received signal to provide an accumulated Q component;

squaring each of said accumulated I component and said accumulated Q component and summing said squares of said accumulated I component and said accumulated Q component; and

noncoherently combining said sum of said squares of said accumulated I component and said accumulated Q component.

12. An apparatus for selecting a synchronized demodulation sequence comprising:

sequence generator means for receiving a first control signal for providing a plurality of demodulation sequences in response to said first control signal;

demodulator means for receiving a received signal and demodulating a received signal in accordance with said plurality of demodulation sequences to provide a plurality of despread signals;

correlator means for receiving said plurality of despread signals and calculating signal correlation energy values for said plurality of despread signals;

searcher controller means for receiving said signal correlation energy values and for providing said first control signal and for providing a second control signal in accordance with said signal correlation energy values; and

wherein said sequence generator means is further for receiving said second control signal and for providing a second plurality of demodulation sequences in response to said second control signal and wherein said second plurality of demodulation sequences are a subset of said first plurality of demodulation sequences.

13. The apparatus of Claim 12 wherein said correlator means comprises accumulator means for receiving said plurality of despread signals and for summing the despread signals over the length of the demodulation sequences.

14. The apparatus of Claim 12 wherein said received signal comprises a first received signal component and a second received signal component and wherein said demodulator means is for receiving said first received signal component and said second received signal component and for demodulating said first received signal component in accordance with a first plurality of demodulation sequences to provide a first plurality of despread signals and for demodulating said second received signal component in accordance with a second plurality of demodulation sequences to provide a second plurality of despread signals and wherein said sequence generator means is for generating said first plurality of demodulation sequences and said second plurality of demodulation sequences.

15. The apparatus of Claim 14 wherein said correlator means comprises:

first accumulator means for receiving said first plurality of despread signals and for summing each of said plurality of despread signals over the length of the demodulation sequences to provide a first plurality of despread sum values;

second accumulator means for receiving said second plurality of despread signals and for summing each of said plurality of despread signals over the length of the demodulation sequences to provide a second plurality of despread sum values;

combiner means for receiving said first plurality of despread sum values and for receiving said second plurality of despread sum values and for combining said first plurality of despread sum values and said second plurality of despread sum values to provide said signal correlation energy values.

16. The apparatus of Claim 15 wherein said combiner means comprises:

squaring means for receiving said first plurality of despread sum values and for receiving said second plurality of despread sum values and for squaring each of said first plurality of despread sum values and each of said second plurality of despread sum values and adding each of said first plurality of squared despread sum values to a corresponding one of said second plurality of squared despread sum values to provide a plurality of energy magnitude values; and

noncoherent combiner for receiving said plurality of energy magnitude values and computing said signal correlation energy values in accordance with said plurality of energy magnitude values.

17. The apparatus of Claim 16 wherein said searcher controller means is further for providing a combination signal and wherein said noncoherent combiner is responsive to said combination signal.

18. A system for selecting a synchronized demodulation sequence comprising:

a sequence generator having an input for receiving a first control signal and having an output;

a demodulator having an input coupled to said sequence generator output and having an output;

a correlator having an input coupled to said demodulator output and having an output; and

searcher controller having an input coupled to said correlator output.

19. The system of Claim 18 wherein said correlator is a coherent accumulator.

20. The system of Claim 18 wherein said sequence generator has a second output and wherein said demodulator has a second input coupled to said sequence generator second output.

21. The system of Claim 18 wherein said demodulator has a second output and wherein said correlator comprises:

a first coherent accumulator having an input coupled to said demodulator output and having an output;

a second coherent accumulator having an input coupled to said second demodulator output and having an output;

a sum of the squares calculator having a first input coupled to said first coherent accumulator output and having a second input coupled to said second coherent accumulator output and having an output;

a noncoherent accumulator having an input coupled to said sum of the squares calculator output.

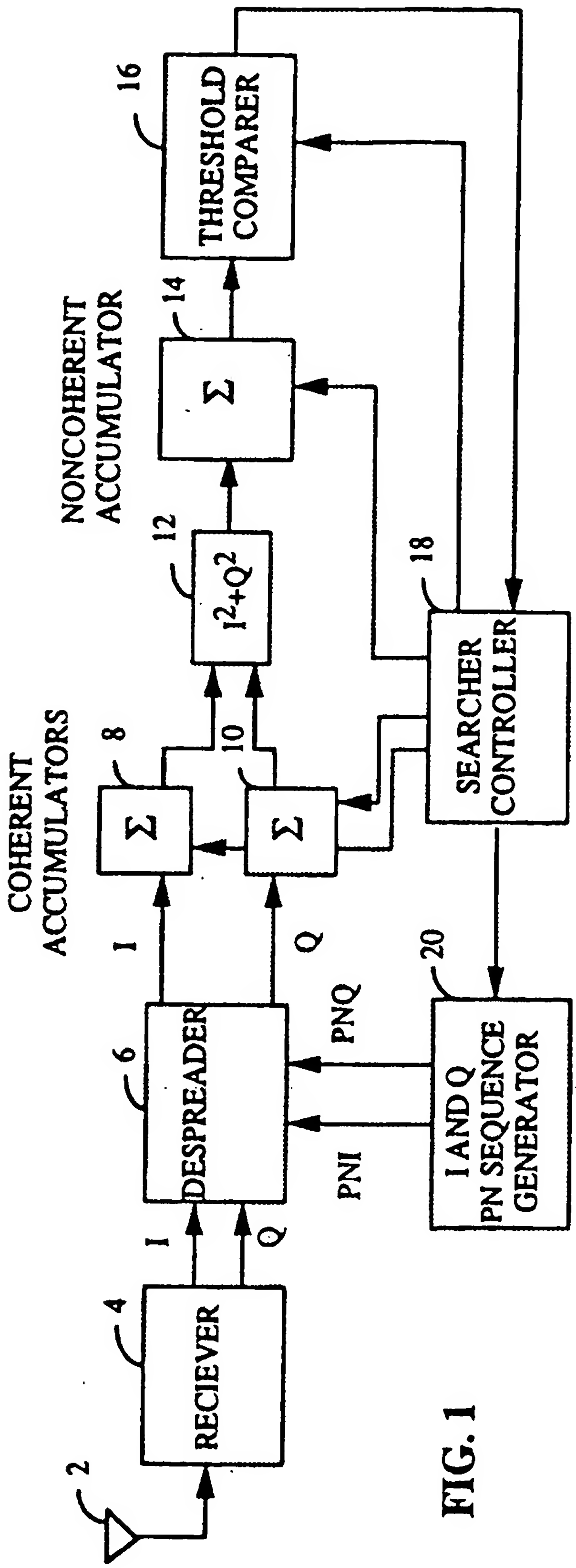
2
4
RECIEVER
I
Q
6
DESPREADER
PNI
PNQ
20
I AND Q
PN SEQUENCE
GENERATOR
I
Q
COHERENT
ACCUMULATORS
8
Σ
10
Σ
12
I^2+Q^2
NONCOHERENT
ACCUMULATOR
14
Σ
16
THRESHOLD
COMPARER
18
SEARCHER
CONTROLLER

FIG. 1

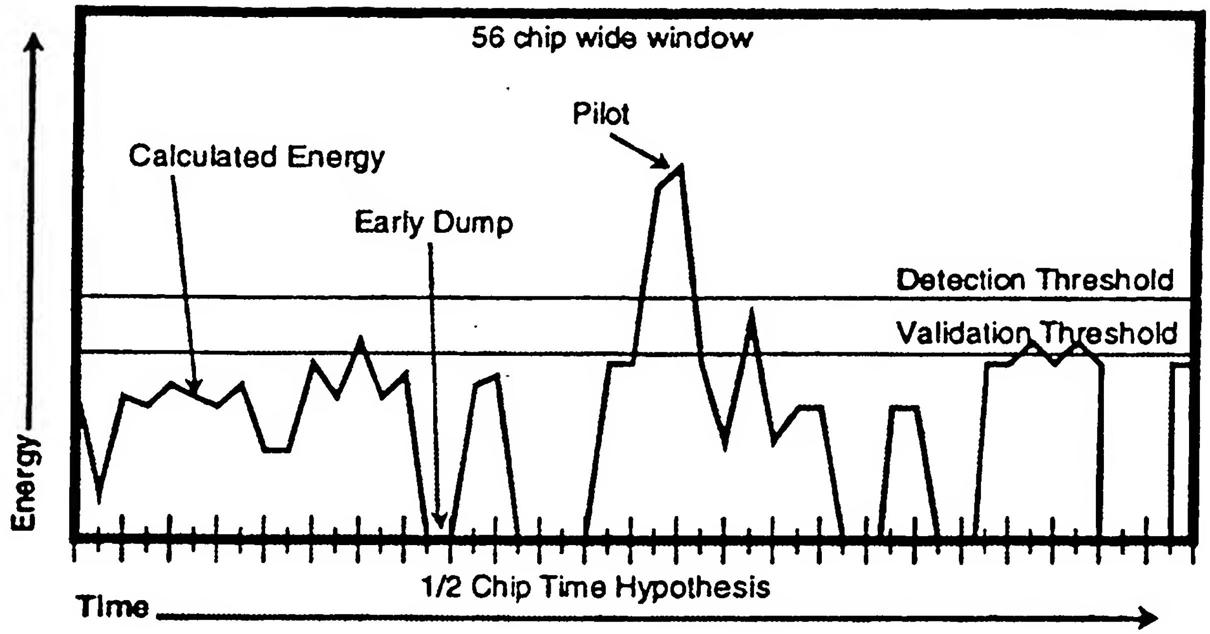
56 chip wide window
Pilot
Calculated Energy
Early Dump
Detection Threshold
Validation Threshold
Energy
1/2 Chip Time Hypothesis
Time

FIG. 2

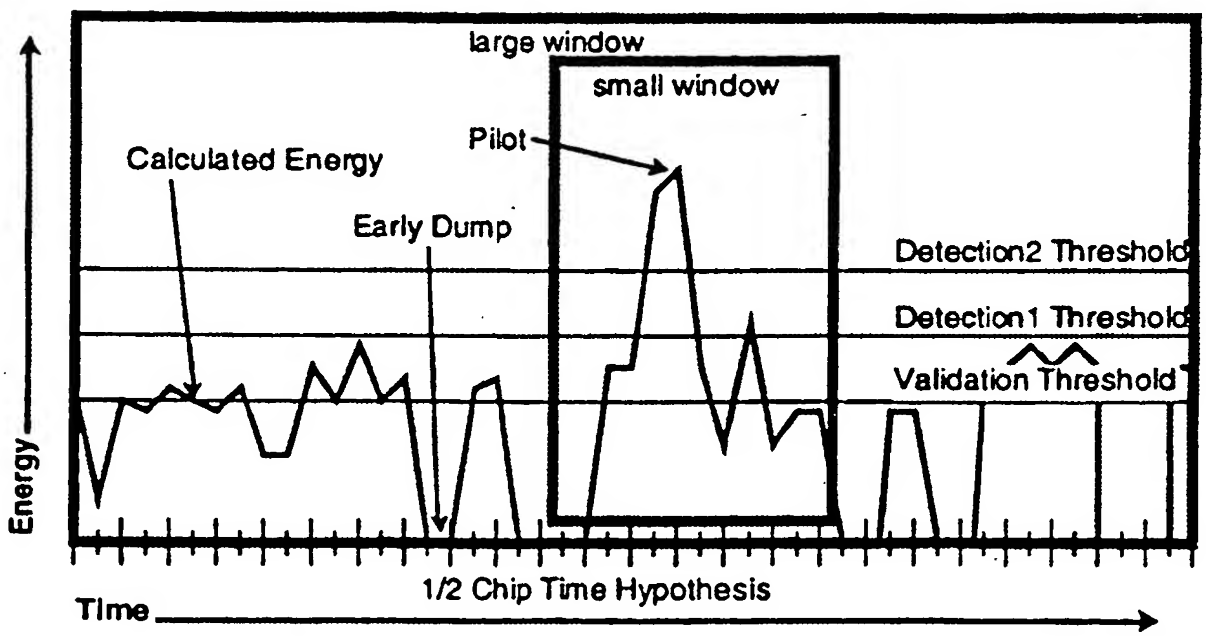
large window
small window
Pilot
Calculated Energy
Early Dump
Detection2 Threshold
Detection1 Threshold
Validation Threshold
Energy
1/2 Chip Time Hypothesis
Time

FIG. 4

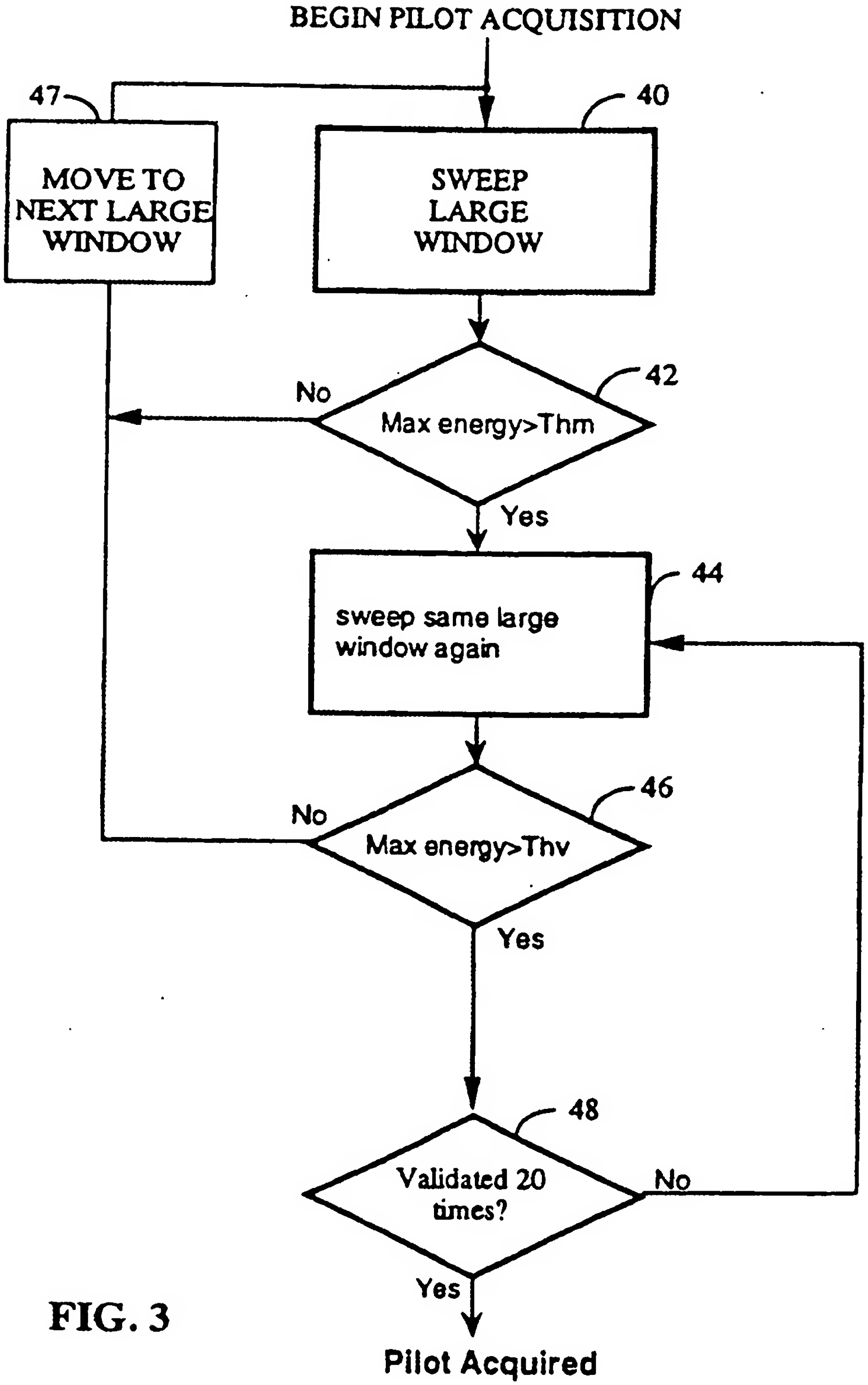
BEGIN PILOT ACQUISITION
47
40
MOVE TO NEXT LARGE WINDOW
SWEEP LARGE WINDOW
42
No
Max energy>Thm
Yes
44
sweep same large window again
46
No
Max energy>Thv
Yes
48
Validated 20 times?
No
Yes
Pilot Acquired

FIG. 3

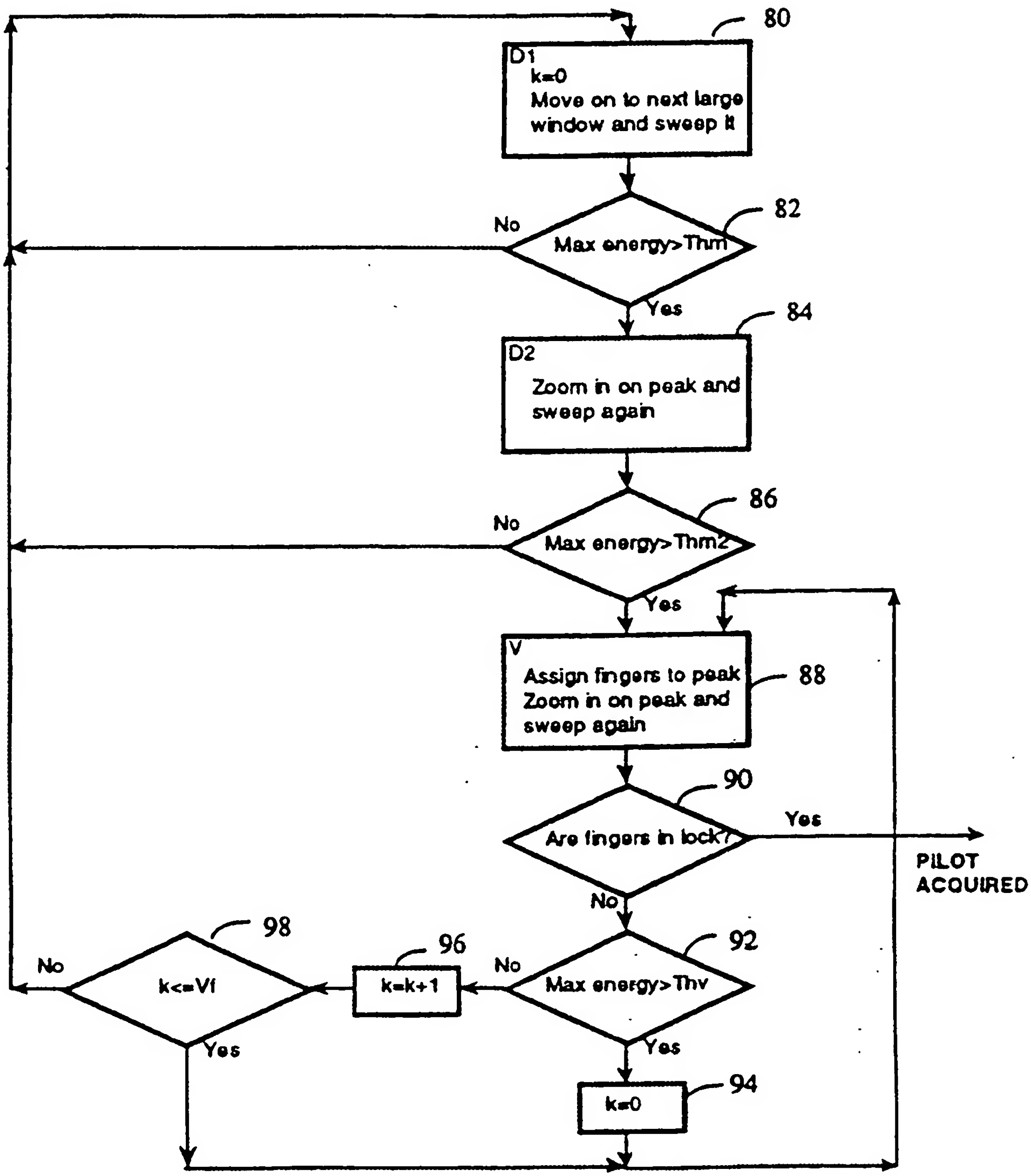
80
D1
k=0
Move on to next large window and sweep it
82
No
Max energy>Thm
Yes
84
D2
Zoom in on peak and sweep again
86
No
Max energy>Thm2
Yes
V
Assign fingers to peak
Zoom in on peak and sweep again
88
90
Are fingers in lock?
Yes
PILOT ACQUIRED
No
92
No
Max energy>Thv
Yes
94
k=0
96
k=k+1
98
No
k<=Vf
Yes

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 95/08659

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO,A,92 00639 (QUALCOMM, INC.) 9 January 1992 cited in the application see page 9, line 7 - line 25 see page 29, line 29 - page 30, line 6 see page 33, line 7 - line 17; figure 7 see page 43, line 17 - line 27 see page 50, line 9 - line 25; figure 9 ---	1,3-10, 12
X	US,A,5 177 765 (HOLLAND ET AL) 5 January 1993 see column 3, line 35 - line 39; claim 2 see column 4, line 5 - line 14 see column 8, line 26 - column 15, line 15; figures 3-8 -----	1,5-9, 12,18

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 November 1995	20.11.95

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 95/08659

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